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Impact of cell texturing quality on cell to module losses

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Abstract

This work is related to a detailed study on the influence of the quality of solar cell texturing on the electrical performance after encapsulation. The effect of texturing on cells front side reflectance was studied for alkaline texturing on Cz wafer materials and processes, acidic textured Cz wafers as well as polished Cz wafers and correlated to the electrical characteristics after encapsulation. The electrical performance on module level was studied indoor at STC (standard test conditions) with varying incident light angles and outdoor during one year of outdoor exposure at a location in southern Germany. To consider for optical effects of glass surface on module performance solar glass with various deep surface texture resp. a flat surface (float glass) were processed and characterized. We show that the degree of texturing hence the front side cell reflection has a small influence on the electrical performance after encapsulation with no measurable incident light angle dependency. Furthermore do we show that even for various textured glasses the cell texturing has no effect on the module performance, neither at STC nor at varying incident light angles. The annual electrical yield study revealed even a better performance for the acidic textured cell modules if compared to the alkaline (hence well textured) cell modules.

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1. Introduction

There is no doubt on the positive effect of cell texturing on solar cell performance determined at STC conditions. The more advanced the level of texturing the less is the reflectance on the solar cell front side resulting in strong efficiency gains. This statement is valid as long as the solar cell is measured under air. For encapsulated cells an increasing degree of texturization leads to a decrease of the optical encapsulation gain hence increasing the cell to module losses [1]. In general it can be stated that cells reflectance is the major loss in air and in the module. Geipel et al. performed a study on 6” mc solar cell modules in which cells were chemically etched by alkaline and acidic processes [2]. Even though the acidic etched solar cells did show a 2.6% higher efficiency if compared to the

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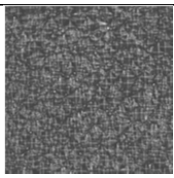
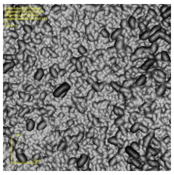
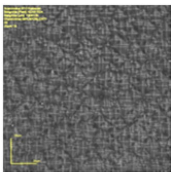
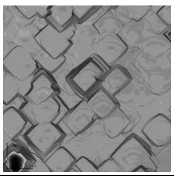
alkaline treated cells no measureable difference in modules STC power and negligible differences for the electrical energy yield were found. The encapsulation losses actually were 2% higher for cells with a higher degree of texturization. Literature data on the modules energy yield and angle dependency is available on a comparison between non-textured mc cells versus textured Cz cells on flat and textured glass and shows that the texturization of cells has none or very little influence on the annual yield for flat and textured solar glass [3]. On the other hand no information is publicly available on how specifically Cz wafer material of different texturing degree if combined with various solar glass (textured, non-textured) electrically performs and influences the cell to module losses. Specifically this knowledge will add to the existing experience on how important the quality of solar cells texturing to the module performance is and aims to questions the attempt of solar cell industry to increase cells performance by optimizing the cells texture further. For this reason mono-crystalline solar cells comprising various texturing levels (weak, strong and polished) were processed and beside the cell to module losses (CTM) the angle dependency and outdoor performance studied in detail. To study further the effect of glass surface on module performance solar glass with various deep surface texture resp. a flat surface were processed and characterized. Furthermore were the reflection on wafer and module level determined.

2. Sample preparation

Cz wafer material was textured with various chemical surface treatments: standard and double texture etching time, acidic etching and polishing to achieve varying levels of texturization. The wafer material was further processed in a standard industrial solar cell process and screen printed with a three busbar front and three pad rear metallization layout. The reflection was determined by a spectrometer after chemical treatment on wafer and module level. For averaging the reflection measurement was taken on four points over the surface (on up to 10 samples) and averaged. Table 1 give an overview on the individual groups, mean reflection on wafer and module level as well as showing the wafer surface after etching.

Table 1. Mean reflection of wafers and modules for four different chemically etched groups.

Group	Note	Wafer surface after etching	Mean Reflection Wafer [%]	Mean Reflection Module [%]
H1	Alkaline etched (standard)		12.85	7.07
H2	Acidic etched		30.44	8.61
H3	Alkaline etched (double)		12.68	7.02
H5	Chemically polished		39.71	13.68

The module sandwich contained standard EVA, white backsheet foil and solar glass. For electrical interconnection the solar cells were soldered with solar ribbon and the leads connected at the edge of the module by four point method. The reflection data clearly shows that lowest reflection can be achieved by alkaline etching resulting in a well defined pyramidal texture even for over-etched wafer material. On the other hand leads acidic etching to poor texturing results as can be seen by wafer mean reflection but with absolutely comparable reflection losses to alkaline etched samples on module level due to the strong light coupling effect inside the module sandwich. The strong coupling effect is also seen on polished wafers but with strongly increased reflection on module level.

In an additional investigation the same chemical wafer treatment was applied but three different solar glasses for module processing used: flat float glass (glass type 3), deep structured Albarino P (glass type 1) and super deep structured Albarino G (glass type 2) solar glass. Figure 1 shows the module setup of the mini-modules. As with the previous experiment cell pieces of the same cell material were placed with 2 mm distance to the cell border to gain best comparability to full cell modules.

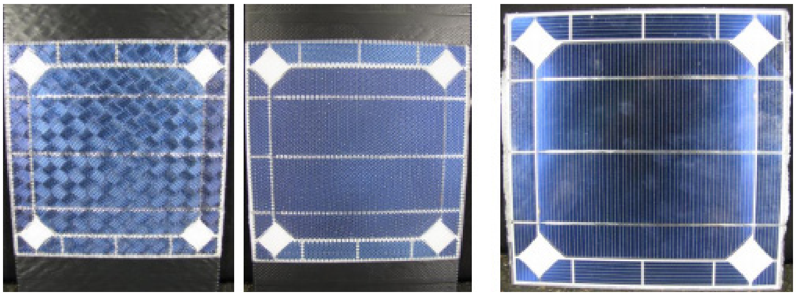


Fig. 1. Module setup for various textured glass: type 2 (left), type 1 (middle) and type 3 (right).

3. Results

3.1. IV and CTM data

The IV curve of the cells and modules was measured using a standard industrial Berger measurement setup. Based on the cells and modules P_{mpp} data the cell to module losses (CTM) were calculated. Figure 2 shows the mean short circuit current I_{sc} of cells and modules (averaged on 10 samples each) for group H1 to H5 including the CTM P_{mpp} losses relative to group H1 (standard texturing).

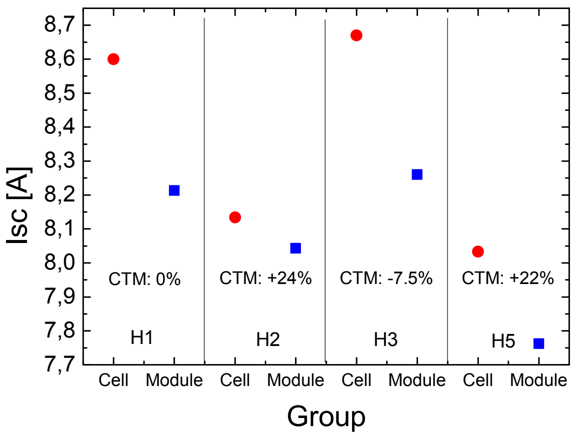


Fig. 2. Short circuit current I_{sc} on cell and module level with CTM losses.

Alkaline etched cells reach on cell as well as on module level almost the same I_{sc} (H1, H3) whereas the acidic etched group shows module I_{sc} values 0.15 A (~ 2%) less compared to the alkaline etched cells with strongest drop as expected for polished wafers. If the CTM loss is referenced to 0% for group H1 (standard alkaline etched group) the modules with over-etched cells show a significantly larger CTM loss whereas acidic and polished wafers show a strong growth of more than 20%. The reason for the larger CTM losses of group H3 compared to H1 is mainly related to the fill factor (see Table 2). In general the over-etching leads to a significantly reduced V_{oc} and FF on cell level for group H3 compared to H1. Group H2 and H5 show strongly reduced I_{sc} losses from cell to module which leads to a gain in relative CTM if compared to group H1. On cell level it has to be mentioned that V_{oc} is increased by 4 mV (group H2) and 5 mV (group H5) if compared to group H1. FF on cell level increases by 0.5%$_{abs}$ for H2 and decreases by 1.2%$_{abs}$ for H5 if compared to H1.

Table 2. Electrical data for cells of groups H1, H2, H3 and H5.

Group	Comment	P_{mpp} [W]	V_{oc} [mV]	I_{sc} [A]	FF [%]	R_{sh} [Ohm]	η [%]
H1	Alkaline etched (standard)	4.19	623	8.60	78.17	154	17.78
H2	Acidic etched	4.01	627	8.13	78.63	246	17.00
H3	Alkaline etched (double)	4.16	622	8.67	77.19	184	17.66
H5	Chemically polished	3.88	628	8.03	76.96	128	16.48

3.2. Normalized angle dependency

The angle dependency of I_{sc} was measured indoor for all modules to determine any angular dependency related to the cell texturing or to the glass surface to occur on module level. Three different glass types were used as described before (type 1, 2 and 3). The cells short circuit current I_{sc} was area-corrected by 1/cos(α) and normalized to the 0° I_{sc} value. Figure 3 shows the normalized light angle dependency averaged for all cell groups on module level for float glass (left picture) and for super deep structured glass (right picture). Absolutely no difference in short circuit current for all measured angles were found. This result clearly demonstrates that from indoor measurement no positive effect for solar cells with pyramid structure texturing may be expected for incident light at larger incident light angles. Small differences at larger angles are a result of the increasing measurement uncertainty which is caused by effects like scattering, etc.

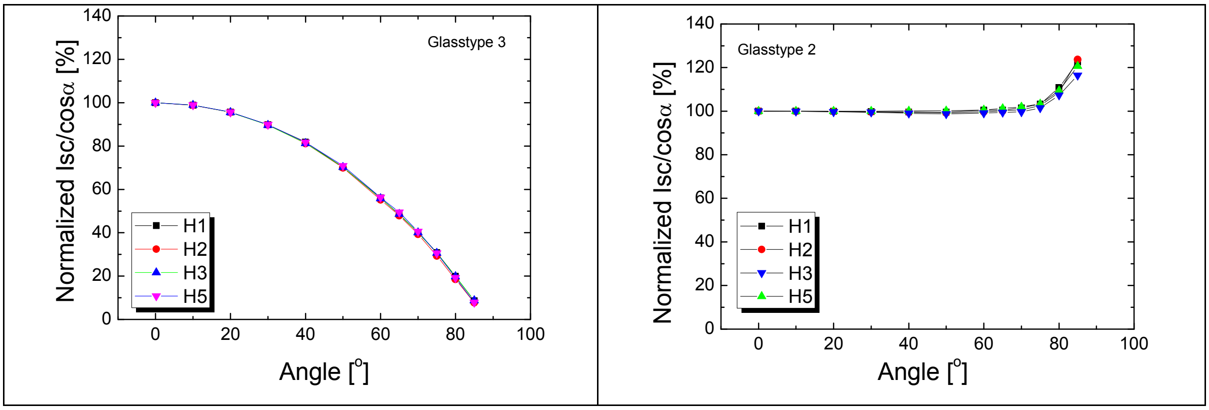


Fig. 3. Angle dependency of normalized I_{sc} for all cell groups with float glass (left) and super deep structured glass (right).

For encapsulated solar cells of acidic (group H2) textured and polished (group H5) wafer material the benefit for larger light angles of structured glass compared to float glass (type 3) is clearly seen in Figure 4. Also it is found that no measurable benefit for different textures exists. Figure 4 shows the normalized light angle dependency averaged for cell group H2 (acidic textured) and group H3 (alkaline textured) for all three glass types. Starting from an angle of approx. 60° and above the performance of glass type 1 and 2 significantly outperforms modules with glass type 3.

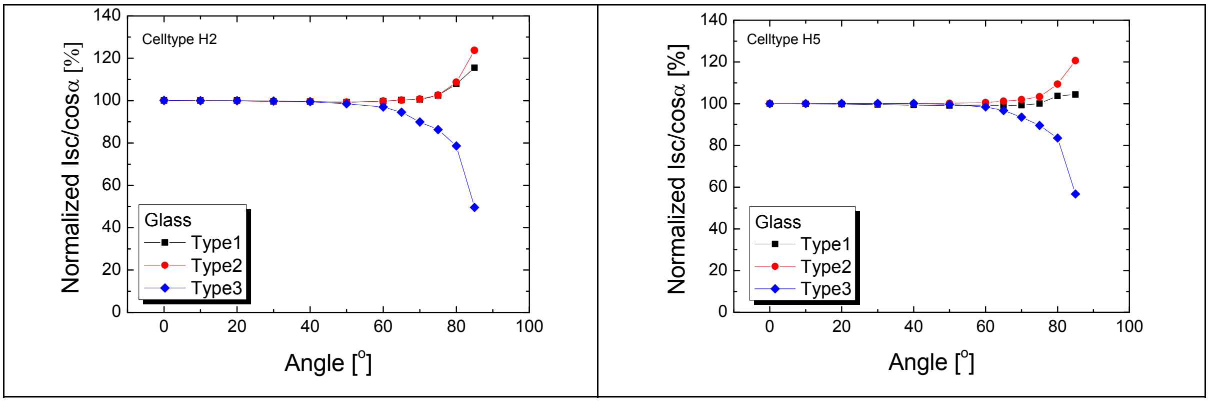


Fig. 4. Normalized angle dependency of normalized I_{sc} for cell type H2 (left) and type H5 (right) for all three solar glass types.

3.3. Outdoor performance

The solar modules produced with float glass (type 3) of various textured solar cells were installed outdoor at a roof location facing 30 degrees south in southern Germany and IV data logged every minute for one year. The performance ratio and energy yield was calculated out of the data and is pictured in Figure 5. In terms of energy yield the results demonstrate a better performance for group H2 and H3 with slightly better results for the acidic etched wafer material in comparison to group H1 and H5. The performance ratio is lowest for group H1 (exhibiting the standard alkaline texture) and almost the same for group H2 and H5 whereas the highest ratio is seen for group H3. According to modules P_{mpp} data we would expect group H1 to outperform all other groups in terms of energy yield, specifically since also no significant difference in the angular light measurement for I_{sc} was found. On the other hand did a detailed evaluation of the outdoor performance over the months of the year and over the light intensity reveal that group H2 and H3 did outperform all other groups in spring, fall and winter months. Only in summer time group H1 showed a superior performance. This is also seen in the light intensity classes if varied in 100 W steps: from 100-300 W/m^2 group H2 and H3 were superior whereas for 400-500 W/m^2 groups H1, H2 and H3 performed the same and only for intensities exceeding 600 W/m^2 group H1 was superior. Taking the angular light measurements into account we assume that V_{oc} and shunt behavior plays the significant role for the energy yield, specifically at lower intensities. V_{oc} for group H2 was 4 mV larger than for group H1 and R_{sh} was highest for groups H2 and H3.

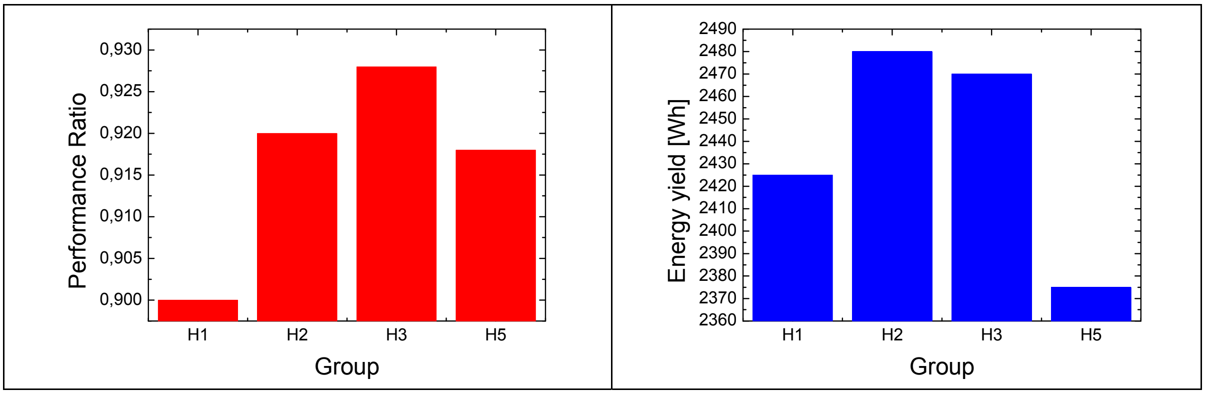


Fig. 5. Performance ratio and energy yield for all groups.

4. Conclusion

This paper conducts a comprehensive study on the performance of solar modules exhibiting solar cells with various wafer textures. Four different chemical wafer treatments were compared: standard alkaline etching, acidic etching, polishing and alkaline over etching in terms of module power, cell to module losses, angular light dependency and electrical yield during one year outdoor performance measurement. Furthermore was textured, super deep textured and float glass included to verify the performance of solar modules with cells of various wafer texturing.

It has been shown that in terms of cell to module losses modules with cells of very low surface texture quality (acidic textured and polished) performed best due to a strong light coupling gain. For these groups V_{oc} and R_{sh} also outperform the other groups. On the other hand the cells P_{mpp} was highest for the alkaline etched cells.

Results for the angular light measurement revealed no significant difference in short circuit current for modules with various cells texturing for two different glasses (structured and float glass). On the other hand were significant differences for two different cell groups experienced for structured and super deep structured glass which is caused by the light coupling effect of the structured surface of the solar glass.

Outdoor performance measurement data revealed the highest energy yield for modules exhibiting solar cells with lowest quality wafer texturing. This data does not correlate to the angular measurement result which showed no difference in short circuit current. On the other hand did low light performance outdoor data and data broken down to the month of the year clearly indicate a superior performance at low light conditions and spring, fall and winter seasons. It is assumed that mainly V_{oc} and R_{sh} are the driving factors for this effect.

In summary this study shows that the quality of wafer texturing is not a key factor for module outdoor performance. Low quality wafer texturing which will lead to less cell power has the potential to increase the amount of produced energy on module level. With this data on hand we strongly encourage the vertical integrated module producer to re-evaluate the cell process to lower the impact of chemical treatment to the solar cell process hence reducing the solar cell process cost.

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